XX. *An account of some experiments with a large voltaic battery. By* J. G. Children, *Esq. F. R. S.*

Read June 15, 1815.

In 1809 I presented to the Society a short account of some experiments performed with a voltaic battery of unusually large plates, which has been honoured by publication in the Philosophical Transactions for that year. Since that period I have constructed another of still larger dimensions, the effects of which form the subject of the present communication. The copper and zinc plates of this apparatus are connected together, in the usual order, by leaden straps; they are 6 feet long, by 2 feet 8 inches broad, each plate presenting 32 square feet of surface. All the plates are attached to a strong wooden frame suspended by ropes and pullies, which being balanced by counterpoises, is easily lowered and elevated, so as to immerse the plates in the acid, or raise them out of it, at pleasure. The first trials of the power of this instrument were made in July 1813, in the presence of several philosophical friends, but the effects then fell very short of my expectations, arising, as I afterwards found, from a defect in the construction, which has been since remedied, and another copper plate added to each member of the series, so that every cell now contains one zinc and two copper plates, and each surface of zinc is opposed to a surface of copper. This was done at the suggestion of Dr. Wollaston, and has very

considerably increased the power of the battery. From some comparative experiments, which I made with a small apparatus, the increase in quantity of electricity, thus effected, is at least one half. The cells of the battery are 21 in number, and their united capacities amount to 945 gallons. To each pole of the battery a leaden pipe, about $\frac{3}{4}$ths of an inch in diameter, is attached by solder, and the opposite end of each pipe immersed in a basin of mercury, (a separate basin for each pipe), by means of which the circuit is compleated, and a perfect contact ensured. The first experiments I shall mention were made on the comparative facility with which different metals are ignited when placed in the electrical circuit. For this purpose, in each experiment, two wires of dissimilar metals were taken, of equal diameter and length; one end of each was in contact with one of the basins of mercury communicating with the poles of the battery, and the other end bent to an angle, and the wires connected continuously by hooking them together. The length of each wire was 8 inches, and the diameter $\frac{1}{30}$th of an inch. The battery was moderately excited by a charge of 1 part acid diluted with 40 parts of water.

Exp. 1. A platina and a gold wire being thus connected, and introduced into the electrical circuit, the platina was instantly ignited, the gold remained unaffected.

Exp. 2. A similar arrangement of gold and silver wires. The gold was ignited, the silver not.

Exp. 3. The same with gold and copper. No perceptible difference in the state of ignition; both metals were heated red.

Exp. 4. Gold and iron. The iron was ignited; the gold unchanged.

Exp. 5. Platina and iron. The iron ignited instantly at the point of contact next the pole of the battery. Then the platina became ignited through its whole extent. After this the iron became more intensely heated than the platina, and the ignition of the latter decreased.

Exp. 6. Platina and zinc. The platina was ignited: the zinc was not; but melted at the point of contact. In a subsequent experiment, the zinc did not melt; but the platina ignited as before.

Exp. 7. Zinc and iron. The iron was ignited: the zinc bore the heat without fusing.

Exp. 8. Lead and platina. The lead fused at the point of contact.

Exp. 9. Tin and platina. The tin fused at the point of contact. No ignition of either wire took place in the two last experiments.

Exp. 10. Zinc and silver. The zinc was ignited before it melted: the silver was not ignited.

The results in every case were the same to whichever pole of the battery either wire was presented. I varied these experiments by introducing several alternations of different wires continuously connected, into the circuit, and obtained in every instance analogous results. Thus

Exp. 11. Alternations of platina and silver, three times repeated: all the platina wires were ignited, and none of the silver.

Exp. 12. One zinc wire between two platina: both the platina wires were ignited, the zinc not.

Exp. 13. One iron between two platina. Both the latter first ignited; then the iron, which soon became most heated, and fused.

It is unnecessary to enter into a farther detail of these experiments; it will be sufficient to say generally, that when wires of several different metals were introduced at once into the circuit, the order of their ignition was precisely that of the former experiments. In one experiment with copper and gold, the copper was decidedly most heated.

I feel some difficulty in attempting an explanation of the preceding phenomena, and offer the following conjecture with diffidence. When a perfect communication is established between the poles of the battery, the electricity circulates without producing any visible effect; but if it meet with resistance in its passage, it manifests itself by chemical action, by the evolution of heat, or both. Thus, if a bar of metal be connected with one pole of the battery, and its extremity immersed in a basin of mercury connected with the other pole, at the instant the surfaces come in contact, heat and light are evolved, which cease as soon as the bar, if it be of sufficient size, is fairly plunged beneath the surface of the quicksilver. If the circuit be completed by two pieces of charcoal, the evolution of heat and light is permanent, as long as their surfaces remain in contact, because that contact can never be so perfect, as to oppose no resistance to the electricity; whereas, in the case of the bar of metal and the mercury, it soon becomes complete, and the current is then uninterrupted. Resistance, therefore, appears to occasion the developement of heat, (whatever be the ultimate cause of the phenomenon,) and as this must be inversely as the conducting power, when any two of the wires connected continuously are placed in the circuit, that which is the worst conductor must be most heated; and thus platina, having the lowest conducting power, is ignited before all the rest; and silver, which

conducts best, is not heated red when connected with any of the other metals. Should it be objected, that if the electricity meet with greater resistance in one body than in the other, equal quantities cannot be transmitted in equal times by the two substances, (a circumstance essential to electrical action,) I answer, that a body may be propelled through two media of different densities, with equal velocity, if the propelling forces be proportionate to the resistances; and it is a necessary consequence that whatever effect the passage of the body be capable of producing in the least resisting medium, it will produce it in a still greater degree in the most resisting; and if that effect be heat, the greatest portion will be developed in the latter instance. In the case in question, indeed, there is but one propelling force; but as it is sufficient to overcome the greater resistance, the analogy is unshaken. That the ignition of the wire is generally first perceptible at the point of contact next the pole of the battery (to whichever pole it be presented) is in favour of the hypothesis. I once thought the phenomena might be owing to the joint effect of difference of conducting power, and inequality of the capacity of different metals for heat; but the experiments of CRAWFORD, LESLIE, DALTON, IRVINE, and others, militate against that idea; for, according to them, the capacities of iron and platina exceed those of all the other metals, whereas, on the supposition alluded to, they ought to be inferior. From the foregoing results, the order of the conducting powers of the metals tried is silver, zinc, gold, copper, iron, and platina. Tin and lead fuse so immediately at the point of contact, that they cannot be placed. Between gold and copper the difference is trifling; and with regard to platina and iron, their

relations to each other, in this circumstance, seem to be affected by elevation of temperature. It may be observed, that the order of the above metals, as conductors of electricity, nearly follows that of their powers to conduct heat.

In an experiment in which equal lengths of two platina wires, of unequal diameter, (the larger being $\frac{1}{30}$, the smaller $\frac{1}{50}$ of an inch,) were placed together in the circuit *parallel* to each other, the thicker wire was ignited, because it conveyed more electricity without proportional increase of cooling surface. When connected continuously, the order of ignition was reversed. These two results were foreseen by Dr. WOLLASTON, who suggested the experiments.

The experiments which I now proceed to mention, were made with the battery in a high state of excitation; and I consider them as representing nearly the maximum of effect which it is capable of producing. As the quantity of acid was increased from time to time, and that previously added often almost spent before fresh was put in, it is not easy to say exactly what proportion it bore to the water; perhaps the largest may be stated at about $\frac{1}{20}$th. On this, as on former occasions, I found a mixture of nitrous and sulphuric acids, to produce the most powerful and permanent effects.

Exp. 1. 5 ft. 6 in. of platina wire, $\frac{11}{100}$ of an inch in diameter, were heated red throughout, visible in full daylight.

Exp. 2. 8 ft. 6 in. of platina wire, $\frac{44}{100}$ of an inch in diameter, were heated red.

Exp. 3. A bar of platina $\frac{1}{6}$ of an inch square, and $2\frac{1}{4}$ inches long, was also heated red, and fused at the end; and,

Exp. 4, a round bar of the same metal, $\frac{276}{1000}$ of an inch

in diameter, and $2\frac{1}{2}$ inches in length, was heated bright red throughout.

Exp. 5. Fine points of boxwood charcoal intensely ignited in chlorine, neither suffered any change, nor produced any in the gas. The result was similar when heated in azote.

I next tried the power of the battery to fuse several refractory substances. The subject of experiment was placed in a small cavity, made in a piece of well burnt boxwood charcoal, floating on the surface of the mercury in one of the basins before mentioned, and the circuit completed by another piece of charcoal, communicating by stout copper wire, with the other basin.

Exp. 1. Oxide of tungsten, which, (as well as all the other metallic oxides operated on,) had been previously intensely ignited in a charcoal crucible, in a powerful furnace, fused, and was partially reduced. The metal greyish white, heavy, brilliant, and very brittle.

Exp. 2. Oxide of tantalum. A very small portion fused. The grains have a reddish yellow colour, and are extremely brittle.

Exp. 3. Oxide of uranium; fused, but not reduced.

Exp. 4. Oxide of titanium; fused, not reduced. When intensely heated it burnt, throwing off brilliant sparks like iron.

Exp. 5. Oxide of cerium; fused, and when intensely heated it burnt with a large, vivid, white flame, and was partly volatilized, but not reduced. The fused oxide, on exposure for a few hours to the air, fell into a light brown powder, containing numerous shining particles of a silvery lustre,

interspersed amongst it, and exhaled an odour, similar to that of phosphuretted hydrogene.

Exp. 6. Oxide of molybdena; readily fused and reduced. The metal is very brittle, of a steel grey colour, and soon becomes covered with a thin coat of purple oxide.

Exp. 7. Compound ore of iridium and osmium; fused into a globule.

Exp. 8. Pure iridium; fused into an imperfect globule, not quite free from small cavities, and weighing 7.1 grains. The metal is white, very brilliant, and in its present state its specific gravity is 18,68, which must be much too low, on account of the porous state of the globule. In the minutes of the experiments, in July 1813, mention is made of the fusion of a small portion of pure iridium into a globule weighing $\frac{62}{100}$ of a grain, which had been previously submitted to the action of a battery of 2000 plates, of four inches square, without melting.

Exp. 9. Ruby and sapphire, were not fused.

Exp. 10. Blue spinel, ran into a slag.

Exp. 11. Gadolinite, fused into a globule.

Exp. 12. Magnesia, was agglutinated.

Exp. 13. Zircon from Norway, was imperfectly fused.

Exp. 14. Quartz, silex, and plumbago, were not affected.

In the year 1796, M. CLOUET converted iron into steel, by cementation with the diamond, with the view of confirming the nature of that substance, and of ascertaining the exact state in which carbon exists in steel. CLOUET had also previously formed steel by cementation with carbonate of lime. Mr. MUSHET repeated this experiment, using instead of the

carbonate, caustic lime, and obtained also what he considered to be cast steel; whence he concluded that the carbon necessary to convert the iron into steel had not been furnished, as CLOUET supposed, by decomposition of the carbonic acid, but that it had found its way from the ignited gas of the furnace to the iron. This result occasioned suspicions of the accuracy of the deductions from the experiment with the diamond; and Mr. MUSHET accordingly, at the suggestion of the editor of the Philosophical Magazine, repeated the experiment made at the Polytechnic School, only *keeping out the diamond.* The results (for he made several experiments) uniformly gave him good cast steel, whence he concludes that we are still without any satisfactory or conclusive proof of the steelification of iron solely by means of the diamond; and adds that he doubts whether the diamond afforded *even one particle of carbon to the iron.* The details of both CLOUET's and MUSHET's experiments, may be found in the fifth volume of the Philosophical Magazine. Sir GEORGE M'KENZIE repeated both CLOUET's experiments and those of Mr. MUSHET, and obtained results confirming the conclusions of the French chemist. The labours of this gentleman indeed seem sufficiently conclusive; but, if a doubt should remain, it occurred to Mr. PEPYS, that the battery would afford an *experimentum crucis* on the subject; and his ingenuity readily suggested a mode of making it, every way unobjectionable. He bent a wire of pure soft iron, so as to form an angle in the middle, in which part he divided it longitudinally, by a fine saw. In the opening so formed, he placed diamond powder, securing it in its situation by two finer wires, laid above and below it, and kept from shifting, by another small wire, bound firmly and

closely round them. All the wires were of pure soft iron, and the part containing the diamond powder, was enveloped by thin leaves of talc. Thus arranged, the apparatus was placed in the electrical circuit, when it soon became red hot, and was kept so for six minutes. The ignition was so far from intense, that few who witnessed the experiment, expected, I believe, any decisive result. On opening the wire, however, Mr. PEPYS found that the whole of the diamond had disappeared; the interior surface of the iron had fused into numerous cavities, notwithstanding the very moderate heat to which it had been exposed; and all that part which had been in contact with the diamond was converted into perfect blistered steel. A portion of it being heated red and plunged into water, became so hard as to resist the file, and to scratch glass. This result is conclusive, for as the contact of any carbonaceous substance, except the included diamond, was effectually guarded against, to that alone can the change produced in the iron be referred. This experiment will also probably be deemed fatal to the opinion of those mineralogists (if any do still maintain that opinion,) who class the diamond with substances of the siliceous genus.

When dry caustic potash was exposed to the intense heat between the two pieces of charcoal, it fused, and appeared to decompose, throwing off a large flame of the peculiar purple red colour, that attends the combustion of potassium. When moist caustic potash was placed in the circuit, the water only was decomposed.

I endeavoured to ascertain if there be any difference in the degree of heat produced at either pole of the battery, by placing two small earthen-ware cups, each containing an equal

weight of mercury, in the circuit, and connected together by a platina wire of such size and length as to be kept constantly ignited. The mercury in the cup connected with the zinc end of the battery, attained in 20 minutes the temperature of 121°; that in the other cup 112°.

The battery, even in its most active state, communicated no charge to the Leyden phial.

I give the following experiment, the last with which I shall occupy the time of the Society, without comment. I separated all the zinc from the copper plates, by dividing the leaden straps that united them; and then by means of other leaden straps, I connected all the zinc plates together as one plate, and all the copper plates in the same manner; thus reducing the whole battery to only two plates, each presenting a surface of 1344 square feet, reckoning the copper surface as only equal to the zinc. When the plates, thus arranged, were suspended, quite out of contact with the acid, a communication was made between the two metallic surfaces by means of a platina wire $\frac{1}{5000}$th of an inch diameter, and about $\frac{1}{30}$th of an inch long, with every possible attention to ensure a perfect contact; but, although the experiment was made in the dark, not the slightest appearance of ignition was perceptible in the minute wire by which these extensive surfaces were connected. It is known, I believe, to almost every member of this society, that Dr. Wollaston has shown, with the delicate apparatus invented by him, that a platina wire, of the same dimensions as that just mentioned, is instantly ignited by a single pair of plates one inch square, on being immersed in a diluted acid. The ratio of the areas of the plates of the respective batteries is as 1 to 48384. When the

plates of the large battery, in the usual order of arrangement, were immersed in mere pump water, previous to any acid having been put into the cells, they ignited $\frac{1}{4}$th of an inch of platina wire $\frac{1}{200}$th of an inch diameter, and fused the end of it into a perfect globule.